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Ecology of the dragonflies at the westernmost spot of Africa, the island of Santo Antão, Cape Verde (Odonata)

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Abstract

From 12 to 25 August 2009, the odonate fauna of Santo Antão, Cape Verde was surveyed by recording adults and collecting larvae and exuviae at 26 localities, mostly situated in the northwest of the island. Based on the results of this survey and literature data on the Cape Verdes it appears that the resident odonate fauna consists of only five species, namely *Anax imperator*, *Crocothemis erythraea*, *Orthetrum trinacria*, *Trithemis annulata* and *Zygonyx torridus*. Three additional species, *Anax ephippiger* and *Pantala flavescens*, which were recorded as single adults in this study, and *Sympetrum fonscolombii*, which was previously recorded in another study, represent seasonal invaders that do not establish permanent populations on the island. Surprisingly, there is no zygopteran species recorded from the island, although a few occur on the neighbouring islands. The breeding habitats of the resident odonates on the island comprise short perennial stream sections in large wadi beds ('ribeiras') that are intensely used for agriculture, as well as artificial irrigation tanks. The odonate assemblage is very uniform, although *Z. torridus* prefers micro-habitats with flowing water and *O. trinacria* is found only in micro-habitats with fine sediments. In the absence of fish, crabs and large water beetles, the larva of *A. imperator* appears to be the top predator in freshwater habitats.

Introduction

Odonates are generally characterised as aquatic insects having an obligatory development in a freshwater habitat. Therefore, one does not expect to find many species in arid regions. However, Odonata occur in deserts everywhere if suitable surface water habitats are available. While there are several studies on odonates

of continental arid regions (see Suhling et al. 2003, 2009 for review) rather little is known about Odonata on arid islands. So far, the best-studied cases are the West Indian islands of Aruba, Curaçao and Bonaire, which were studied by Geijskes (1935) and the island of Soquotra east of the Horn of Africa that was surveyed by Schneider & Dumont (1998). The waters in arid regions are marked by a strong gradient given by the degree of permanency of the water. Simple patterns of habitat predictability and duration of flooding are the main determinants for the establishment of odonate assemblages (Padeffke & Suhling 2003; Johansson & Suhling 2004). In the case of arid islands one can predict that the patterns typical for arid regions should be augmented by island effects. Besides geographical isolation there might be the absence of fish predation as a major driver for diversification, which results in inhabitants being more generalists within the water permanence gradient (Wissinger et al. 2009).

The Cape Verde Islands are situated in the Atlantic Ocean ca 500 km west of Senegal, and have an arid climate. The odonate fauna of the archipelago is not well known. So far, only 14 species have been recorded from Cape Verde (Aistleitner et al. 2008). Additionally, the database is not good enough to distinguish between the effects of poor knowledge, geographic isolation, and habitat suitability.

At the beginning of this study the aim was simply to describe Odonata assemblages on an African island and to add new species to the Cape Verde checklist. Santo Antão is the second biggest island situated in the northwest of the archipelago and is known to have permanent waters. The first odonate collections from Santo Antão were made by E. Bauer and B. Traub in 1978 (Lobin 1982) and Aistleitner et al. (2008) list seven species for the island. However, the database is very poor and I soon realised that the breeding odonate diversity was not rich. As a seasonal effect could be excluded, I therefore added the question: Why is the odonate fauna of Santo Antão Odonata so species-poor?

Material and methods

Study area

Santo Antão is the westernmost and northernmost island of the Cape Verde Archipelago. It is entirely of volcanic origin and comprises 779 km^2. Because of higher elevations (max. 1,900 m a.s.l.) it is wetter than the other northern islands of the archipelago, the so called Windwards ('Barlavento'). The deep, incised, dry valleys ('ribeiras') in the northeast of Santo Antão have more vegetation and some have stretches with permanent water.

The climate is characterized by moderate stable temperatures and aridity, determined by the cold Canary Current and the northeast trade wind (ca 80% of the winds), the southwest monsoon (ca 5%) and the Harmattan (ca 6%). In general,

most of the rain is caused by the monsoon and falls between August and October. The amount of rain may vary considerably from year to year (Knapp 1973; Lobin & Ohm 1987), because the monsoon does not always reach the Cape Verde Islands.

Methods

In order to describe Odonata assemblages, data on adults, larvae and exuviae were recorded at each locality. Because most species are easily identified in the field, collecting of adults was kept to a minimum. At most localities exuviae were collected. Larvae as well as other macroinvertebrates were sampled by using a strainer. In most cases this larval sampling was done to provide presence/absence data at a given habitat and to evaluate reproductive success at a local site or river catchment.

Data on reproductive activity of adults were recorded at all waters, and intensive sampling and measuring of larvae in two water bodies were made to obtain data on life-cycle phenology and seasonal developmental characteristics. The head width of the larvae was measured in the field to the nearest 0.01 mm using a dial calliper. In the case of *Zygonyx torridus*, which exhibits a wide range in the size of final-stadium exuviae (also observed in arid Namibia -AM unpubl.), both head width and body length were measured. In order to understand food-web patterns, several odonate larvae were kept in small containers and fed with *Bufo regularis* tadpoles of different size as well as chironomid and ephemeropteran larvae.

Twenty six localities were investigated (Table 1). Names are given according to the map 'Santo Antão, Kap Verde, Goldstadt Wanderkarten, 1: 50,000' (Goldstadt Verlag 2006, ISBN 3-89550-467-X) and to information of local aluguer (shared taxi) drivers. Coordinates and altitudes were ascertained by GPS in the field and adjusted to Google Earth (http://earth.google.com) data due to wide deviations in the narrow valleys. Authorities of species recorded from Cape Verde are given in Results and Table 4.

Results

Seven Odonata species were found on the island of Santo Antão. Five of the species were recorded as adults, larvae and exuviae, often simultaneously at the same locality. There was no record of larvae or exuviae of species not known as adults. In August 2009 all five species were reproductively active, indicated by observations of copulations or ovipositions. No zygopterans were recorded, either as adults or exuviae, or as larvae during extensive sampling of macroinvertebrates. Two species were recorded as single individuals only. A female *Anax ephippiger* (Burmeister) was found dead, but coloured as alive at loc. 21 in the vegetation at the stream. A single *Pantala flavescens* (Fabricius) was observed flying above a road in the mountains (loc. 14).

Table 1. Localities on Santo Antão, Cape Verde that were surveyed in August 2009. RC: river catchment; Alt: altitude [m a.s.l.]; D: date of visit in August 2009.

	RC	Locality	Habitat	Coordinates	Alt	D
1	Ribeira da Cruz	Ribeira da Cruz	Irrigation tank at the aqueduct	17°06.34'N, 25°14.44'W	317	18
2	Ribeira da Garça	Garça de Cima; nameless springbrook of the Ribeira da Garça	Small cascade in a taro cultivation	17°06.37'N, 25°09.54'W	635	21
3	Ribeira da Garça	Manta Velha	Irrigation tank	17°07.39'N, 25°09.61'W	378	17
4	Ribeira da Garça	Manta Velha	Stream below the village, stream bypassing the road	17°07.50'N, 25°09.47'W	337	17
5	Ribeira da Garça	Chã de Igreja	Dry river bed before the street ascends to the plain of Chã de Igreja	17°08.61'N, 25°09°91'W	156	17
6	Ribeira de Fontainhas	Fontainhas	Right tributary of the Ribeira de Fontainhas east of Fontainhas	17°11.34'N, 25°06.14'W	233	16
7	Ribeira Grande	Pedracin Village	Irrigation tank in banana plantation	17°09.63'N, 25°07.31'W	216	12
8	Ribeira Grande	Pedracin Village	Irrigation tank at hotel entrance	17°09.69'N, 25°07.25'W	233	12, 14, 15
9	Ribeira Grande	Pedracin Village	Irrigation tank in sugar cane field	17°09.71'N, 25°07.16'W	219	12, 14, 21
10	Ribeira Grande	Caibros	Tributary of the Ribeira Grande	17°08.16'N, 25°07.60'W	365	21
11	Ribeira de André Frances, tributary of the Ribeira Grande	Chã de Pedras	Levadas	17°08.13'N, 25°06.73'W	301	21
12	Ribeira de André Frances, tributary of the Ribeira Grande	Chã de Pedras	Puddles in irrigated taro cultivation	17°08.13'N, 25°06.73'W	280	21
13	Ribeira Grande	Ribeira Grande	Brackish pools in the mouth of the wadis Ribeira Grande and Ribeira do Tore at the coastal shore	17°11.07'N, 25°03.80'W	3	24

RC	Locality	Habitat	Coordinates	Alt	D
14 -	-	Road between Ribeira Grande and Corda near Fujã Roadonda	17°10.25'N, 25°04.50'W	500	24
15 Ribeira de Torre	Xôxô	Stream with rocky pools below Xôxô, water running over the road, taro cultivation	17°08.60'N, 25°04.14'W	254	14, 19
16 Ribeira Mão para Trás	Mão para Trás	Rocky pools in a stream used for irrigation	17°10.42'N, 25°03.30'W	51	23
17 Ribeira Mão para Trás	Mão para Trás	Irrigation tank	17°10.60'N, 25°03.24'W	25	23
18 Ribeira do Paúl	Chã de João Vaz	Stream at the ford	17°07.42'N, 25°02.88'W	402	13, 25
19 Ribeira do Paúl	Passagem	Rocky stream at the ford, taro cultivation	17°07.97'N, 25°02.47'W	250	13, 15, 22
20 Ribeira do Paúl;	Passagem	Big irrigation tank	17°08.00'N, 25°02.43'W	266	22
21 Ribeira do Paúl	Perda dos Mosos	Stream at the bridge, taro cultivation	17°08.50'N, 25°02.27'W	137	13
22 Ribeira das Pombas	Lombo das Pontas	Stream below the cascade	17°07.61'N, 25°02.24'W	330	20
23 Ribeira das Pombas	Lombo das Pontas	Irrigation tank	17°07.60'N, 25°02.02'W	303	20
24 Ribeira das Pedrinhas	Lombo das Tintas	Dam at the costal road, taro cultivation	17°07.48'N, 24°59.84'W	32	13
25 Ribeira de Janela	Ribeira de Janela	Stream at the coast, taro cultivation	17°07.31'N, 24°59.69'W	25	13
26 Ribeira das Patas	Curral das Vacas	Irrigation tank N of the cemetery	17°02.63'N, 25°13.12'W	806	18

The following data refer to the locality numbers and date of recording as indicated in Table 1 and Figure 1. When a species was recorded at a locality on all days of inspection of the site no further distinction is made; otherwise the data are presented with the locality number added by small type a, b, c in temporal order.

Anax imperator Leach

Adults were regularly present, flying above the road in the Ribeira do Paúl as well as in the cultivated areas of other ribeiras. Larvae of this species were the most abundant among the odonates, recorded in high numbers and different stadia

(Fig. 2, Table 2) in aquatic vegetation as well as on rocky surfaces in pools. *A. imperator* adults were the only odonates recorded at water at dusk (loc. 8).
Adults at locs 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25.
Exuviae at locs 6, 7, 8, 9, 10, 11, 15, 16, 18, 20, 22, 23, 26.
Larvae at locs 6, 15, 16, 19, 23.

Crocothemis erythraea (Brullé)

Adults were recorded emerging as well as exhibiting reproductive behaviour.
Adults at locs 1, 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 15, 17, 18, 19, 20, 25, 26.
Exuviae at locs 1, 4, 6, 7, 8, 10, 15, 16, 26.
Larvae at locs 6, 15, 16, 22.

Orthetrum trinacria (Selys)

Larve were found in mud and fine detritus only. Larve kept in small containers fed on small tadpoles of *Bufo regularis* , as did larvae of *A. imperator*, *C. erythraea* and *T. annulata*.

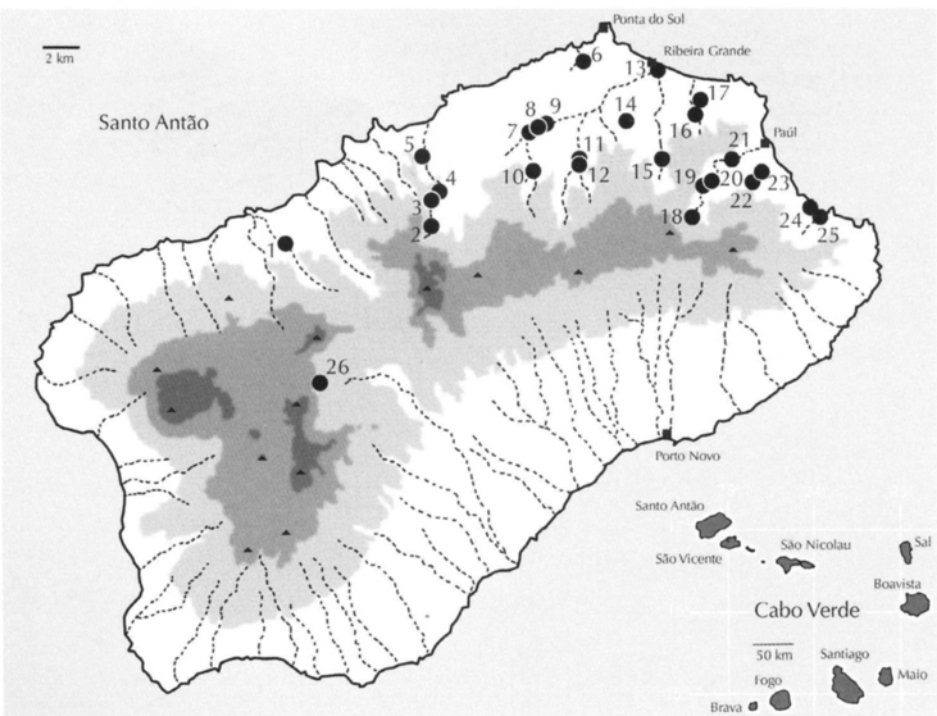

Figure 1: Map of the island of Santo Antão, Cape Verde Islands, with all recording sites of Odonata in this study.

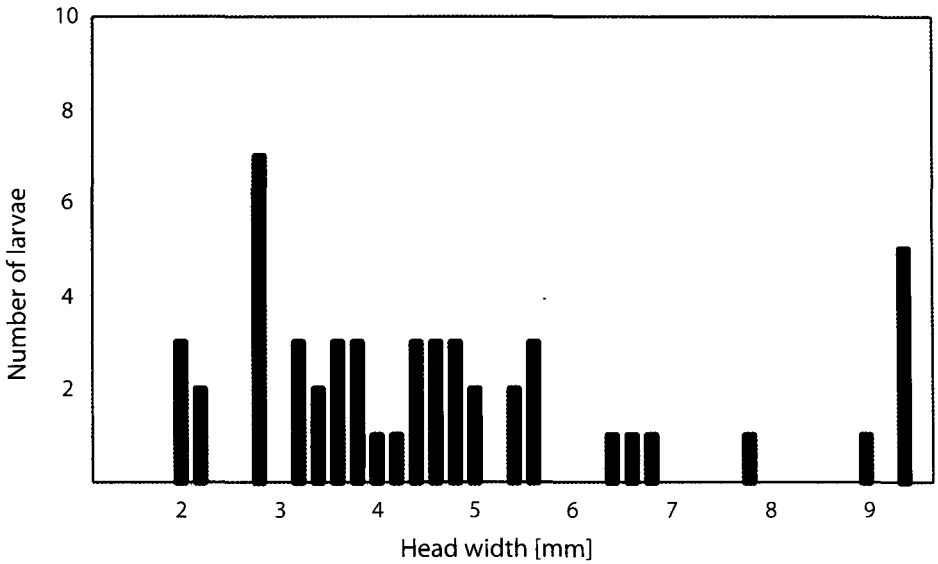

Figure 2: Size frequency of *Anax imperator* larvae (n = 51) in a rocky stream section of the Ribeira do Paúl at the ford near Passagem (loc. 19) on 22 August 2009.

Adults at locs 1, 3, 4, 6, 7, 8, 9, 10, 11, 12, 15a, 16, 17, 18a, 19, 20, 21.
Exuviae at locs 1, 7, 15, 26.
Larvae at locs 6, 15, 16, 23.

Trithemis annulata (Palisot de Beauvois)

Adults were observed emerging as well as exhibiting reproductive behaviour. Larval size showed a wide variance (Table 2).

Table 2. Samples of Odonata larvae in a 20 m section of the Ribeira de Torre below Xôxô (loc. 15) on 19 August 2009.

Species	Range of head width [mm]	Total number
Anax imperator	1.9 - 9.4	38
Crocothemis erythraea	3.1 - 5.9	4
Orthetrum trinacria	1.9 - 3.8	7
Trithemis annulata	1.4 - 4.6	37
Zygonyx torridus	2.0 - 7.4	28

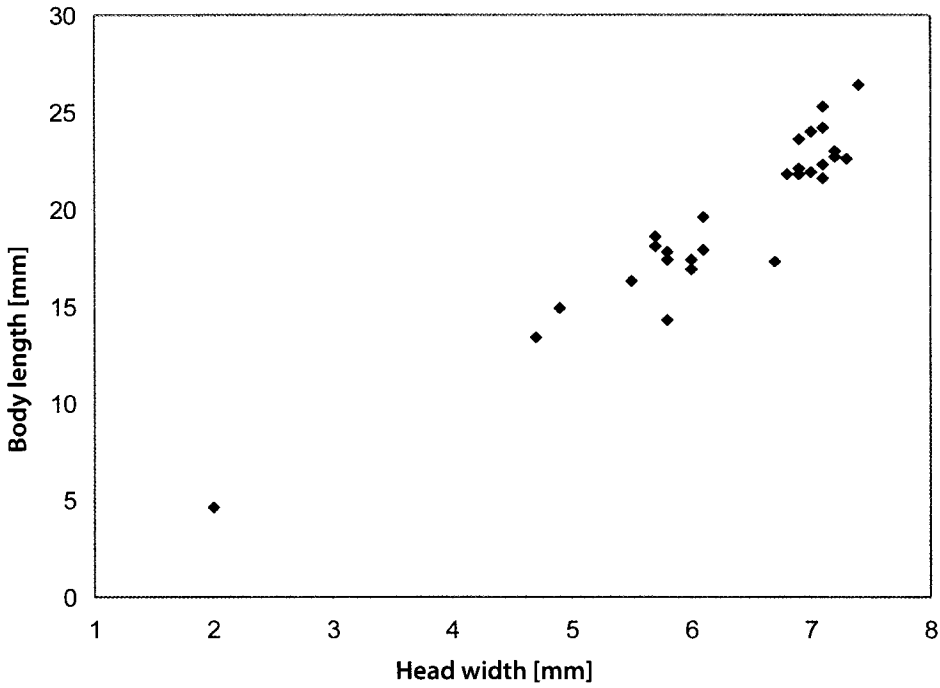

Figure 3: Relation of head width and body length in a sample of *Zygonyx torridus* larvae (n = 28) in a 20 m section of the Ribeira de Torre below Xôxô (loc. 15) on 19 August 2009.

Adults at locs 1, 2, 3, 4, 5, 6, 7a, 9, 10, 11, 12, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25.
Exuviae at locs 1, 4, 6, 7, 10, 15, 16, 17, 18, 19, 26.
Larvae at locs 6, 15, 16, 19, 22.

Zygonyx torridus (Kirby) (Plate IVa)

Larvae were recorded in streams at riffle stretches and small rapids by disturbing them by hand or a twig and collecting the drifting larvae with a strainer. In one case several (loc. 23) live larvae were recorded in an irrigation tank. Larvae have a large variation in the relation between head width and body length in later stadia (Fig. 3). In August 2009 the number of males patrolling at water was low, and in several catchments adults were only seen flying far away from water. Oviposition was observed only once (loc. 19; 22 viii 2009).
Adults patrolling at water were recorded at locs 2, 4, 11, 15a, 19; adults in terrestrial habitats were recorded near locs 6, 7a, 10.
Exuviae at locs 10, 11, 15, 16, 18, 19, 20.
Larvae at locs 2, 15, 16, 19, 22, 23.

Discussion

The odonate fauna of Santo Antão is poor. This first survey of Odonata on a Cape Verde island showed that in August five species occured at almost all river catchments on the island (Table 3). The great number of recorded exuviae and larvae indicate that these species breed there successfully. The simultaneous presence of larvae in different stadia (Figs 2, 3, Table 2) and adults showing reproductive behaviour combined with the low variation in temperatures indicate that these species lack strict seasonality. Beside this group of five species two species were recorded only once and merely as single adults, while a third one known from the island was not found in this study. These exceptions were *Pantala flavescens* which was recorded only one time far away from water, *Anax ephippiger* which was recorded only as a single specimen – based on this record the species is new for the island -, and *Sympetrum fonscolombii* (Selys) which is only known from other periods of the year (Table 4). Surprisingly, no zygopteran is known from the island so far, although *Ischnura senegalensis* (Rambur) and *Lestes pallidus* Rambur have been recently recorded from the neighbouring island of São Vicente (Aistleitner et al. 2008).

Table 3. Distribution of Odonata species in 11 ephemeral river catchments of Santo Antão. x: previous records, Lobin (1982), Aistleitner et al. (2008); grey cells: this study.

Catchment	*A. imperator*	*C. erythraea*	*O. trinacria*	*T. annulata*	*Z. torridus*	others
Ribeira da Cruz						
Ribeira da Garca			x			*P. flavescens*
Ribeira de Fontainhas						
Ribeira Grande	x	x	x	x		
Ribeira de Torre	x			x	x	
Ribeira Mão para Trás	x				x	*S. fonscolombii*
Ribeira do Paúl	x			x		*A. ephippiger, S. fonscolombii*
Ribeira das Pombas						
Ribeira das Pedrinhas						
Ribeira de Janela						
Ribeira das Patas						

Table 4. Known flying season of 11 Odonata species on the Cape Verde Archipelago, data based on Aistleitner et al. 2008, Martens & Hazevoet 2010 and this study. The data from Santo Antão are marked dark grey.

Species	J	F	M	A	M	J	J	A	S	O	N	D
Lestes pallidus Rambur												
Ischnura senegalensis (Rambur)												
Anax ephippiger Burmeister												
Anax imperator Leach												
Crocothemis erythraea (Brullé)												
Orthetrum trinacria (Selys)												
Pantala flavescens (Fabricius)												
Sympetrum fonscolombii (Selys)												
Tramea limbata (Desjardins)												
Trithemis annulata (Palisot de Beauvois)												
Zygonyx torridus (Kirby)												

Inland waters

On Santo Antão most inland surface waters are situated northwest of the main mountain chain that catches the monsoon clouds. In August 2009 most running waters consisted of short stretches of shallow streams. The only exception was the Ribeira do Paúl, which was more or less permanently flowing along the valley. Due to the introduction of plastic hoses for irrigation, the small, old irrigation canals ('levadas') have declined rapidly and have lost their relevancy as secondary habitats for the aquatic fauna on the island. Irrigation tanks are the most frequent lentic waters. They often exhibit high diurnal dynamics of the water level, depending on emptying and filling. Other lentic water bodies existed as rock pools in river beds and swamp-like waters in taro cultivations.

No indigenous fish occur on Santo Antão, and no introduced freshwater fish are known to exist. There are also no crab or shrimp species known from the Cape Verde freshwaters. These facts may be caused by the absence of coastal swamps on the steep coast and the ephemeral character of the main drainages, which do not allow a colonization of freshwater tolerant species from the sea. Aquatic beetles of larger body size are rare on the islands. Therefore, Odonata constitute the top predators in the freshwaters of Santo Antão. The introduction of the African leopard toad *Bufo regularis* Reuss (Schleich 1987) may have enhanced the larval

populations of the odonate species known from the island. *Crocothemis erythraea*, *Orthetrum trinacria*, *Trithemis annulata* and especially *Anax imperator* may benefit from the large numbers of different sizes of easily catchable tadpoles.

Geographical isolation and species composition

Santo Antão is the westernmost island of the Cape Verdes and the westernmost spot of Africa, more than 835 km from the coast of continental Africa. The main winds blow from the sea from the northwest, whereas winds coming from the African continent only occur in the dry season. The so-called Harmattan is a dry and dusty West African trade wind, blowing south from the Sahara. Therefore, there is no coincidence of seasonal rainfall and odonate immigration from more humid parts of Africa, as is known from the Namib desert (Suhling et al. 2009). Besides the geographical isolation and the arid climate, the major wind direction will have a negative effect on odonate colonization.

Apart from the circumtropical migrant, *P. flavescens*, the odonate species recorded from Santo Antão belong to a group of widespread African representatives, which are mobile (Suhling et al. 2009) and well known from other African islands (Blackman & Pinhey 1967; Pinhey 1976; Báez 1985; Schneider & Dumont 1998; Couteyen & Papazian 2002) as well as from arid African regions (Suhling et al. 2003, 2009). However, the list of such species is much longer than the list of Santo Antão species (see below).

Residents and migrants

Five species have been recorded as larvae in very different size classes, as exuviae and as adults at the end of the dry season: *A. imperator*, *C. erythraea*, *O. trinacria*, *T. annulata* and *Zygonyx torridus*. Therefore, thespecies form the group of 'residents'. They probably inhabit the freshwater habitats of Santo Antão permanently, mostly by being reproductively active and forming larval populations in all seasons of the year, although the presently available data on odonate phenology on the Cape Verdes are too scanty (Table 4) to conclusively support this hypothesis.

Z. torridus is restricted to lotic waters, where the majority of larvae were recorded on rocks and in detritus in flowing stretches and small rapids. There were no larvae in pool sections. *O. trinacria* successfuly breeds in waters with fine sediments only. The other species, *A. imperator*, *C. erythraea*, *T. annulata*, have a wide spectrum of habitats, from lotic to lentic waters and from vegetated water bodies to bare rockpools. Therefore, all suitable habitats seem to be occupied.

The 'migrants' so far known consist of *A. ephippiger*, *S. fonscolombii* and *P. flavescens*. They may have temporary breeding success depending on invasions from the African mainland and rainfall. Because of their rapid development (Padeffke & Suhling 2003; Suhling et al. 2004) they are able to outcompete the resident fauna

at newly established temporary waters (Padeffke & Suhling 2003), whereas at permanent waters their breeding success is limited by predation by the resident fauna.

Odonates not recorded from Santo Antão but known from other African islands

There is a long list of odonate candidates for Santo Antão: *Agriocnemis exilis* Selys, *Ceriagrion glabrum* (Burmeister), *Ischnura senegalensis*, *Lestes pallidus*, *Diplacodes lefebvrii* (Rambur), *Orthetrum chrysostigma* (Burmeister), *Tholymis tillarga* (Fabricius), *Tramea basilaris* (Palisot de Beauvois), *T. limbata* and *Trithemis arteriosa* (Burmeister). Three species have recently been recorded from other Cape Verde islands: *I. senegalensis* from São Vicente and Boavista, *L. pallidus* from São Vicente, Boavista and Sal, and *T. limbata* which was recorded on Boavista in 2001 (Aistleitner et al. 2008). *T. arteriosa* has not been recorded from the Cape Verdes for more than hundred years (Martin 1908; Aistleitner et al. 2008), The other species are not known from the Cape Verde Islands so far, although all these species belong to a group of widespread and mobile African representatives recorded from other African islands (Blackman & Pinhey 1967; Pinhey 1976; Báez 1985; Schneider & Dumont 1998; Couteyen & Papazian 2002) as well as from arid regions (Suhling et al. 2003, 2009).

There are two different explanations for the lack of the species listed above. One is geographical isolation, with long distances from colonizing areas, the lack of stepping-stone habitats and an unsuitable combination of winds and humidity (see above). The other major explanation might be a general pattern in island biogeography: When the the aquatic fauna on islands is species-poor, the present species have a wider ecological niche and act more generalistic than conspecifics on the mainland, especially within the water permanence gradient (Wissinger et al. 2009). It is suggested that this might be based on the unpredicatibilty of drying and the absence of fish predation as a major driver for diversification (Wissinger et al. 2009). The concept of wider niches in island colonizers is especially obvious in the genus *Orthetrum*: One can suggest that *O. chrysostigma*, which represents the genus on the Canaries and Soquotra (Báez 1985; Schneider & Dumont 1998) and is common in West Africa (Suhling et al. 2003), may have no open niche, because its larval habitat, fine sediments, is occupied by *O. trinacria*.

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